Closing in on Supermassive Black Holes in ActiveGalaxies

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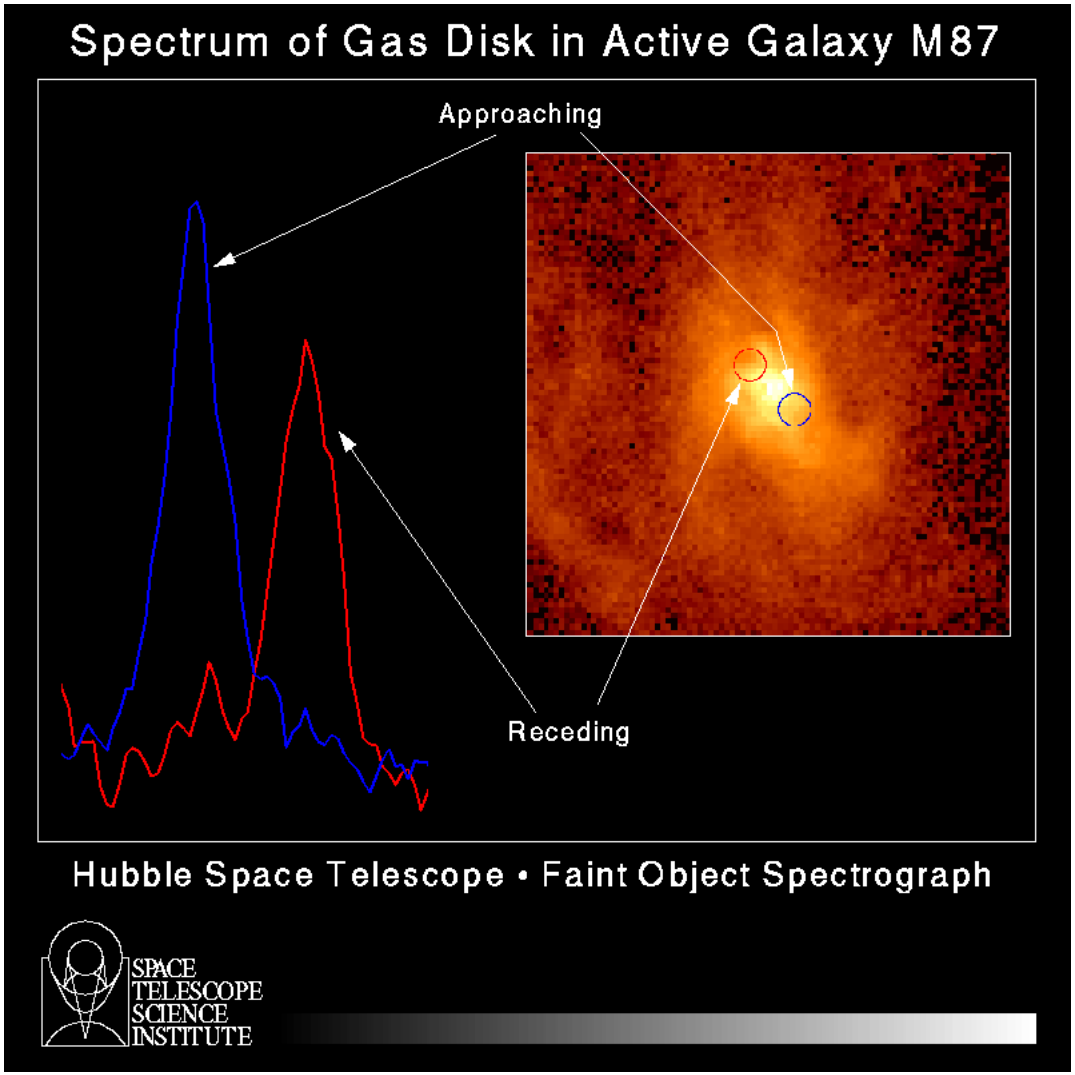
Supermassive black holes have long been thought to exist in the centers of galaxies, providing the power behind active galactic nuclei (AGN) via the release of gravitational energy sustained by an accretion disk. Although direct evidence for supermassive black holes has remained elusive, the indirect evidence is strong. Recent observations indicate a significant amount of gas around the cores of galaxies. Not only do we witness "galactic cannibalism", where material is acquired as the result of a merger, but we see large, dusty disks that often obscure the galactic nucleus. Using the motions of this gas to probe the vicinity of supermassive black holes has been a significant achievement in astronomy.

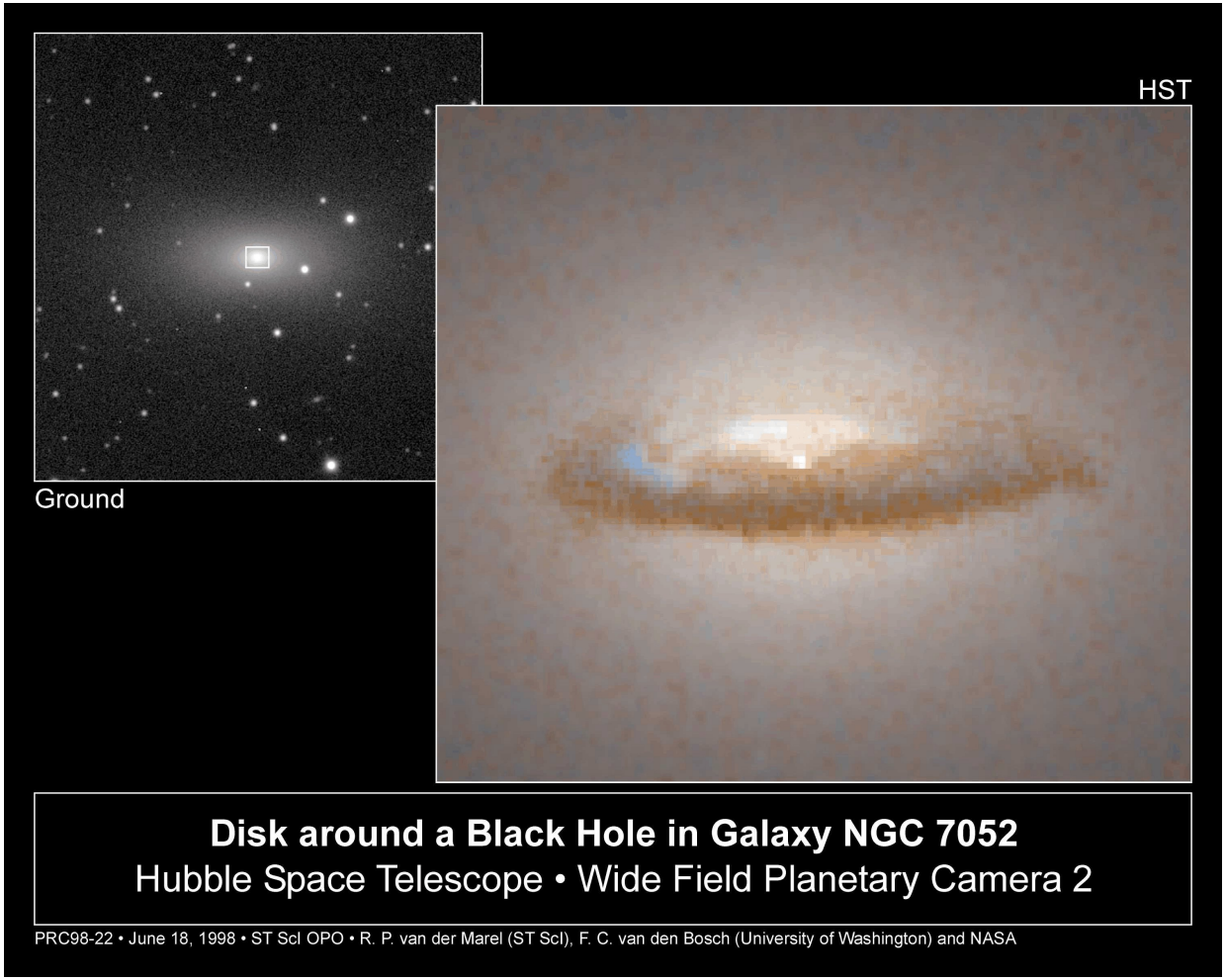
The hard X-ray emission of AGN is thought to arise from flares in a hot corona associated with the accretion disk. These X-rays often illuminate the underlying disk, and the subsequent reflection imprints atomic features into the spectrum, most notably the fluorescent iron K line at 6.4 keV. Reflection can also arise from the large-scale gas disk or torus. X-ray observations of bright, nearby AGN have revealed the Fe K line to

Gas Orbiting a Black Hole



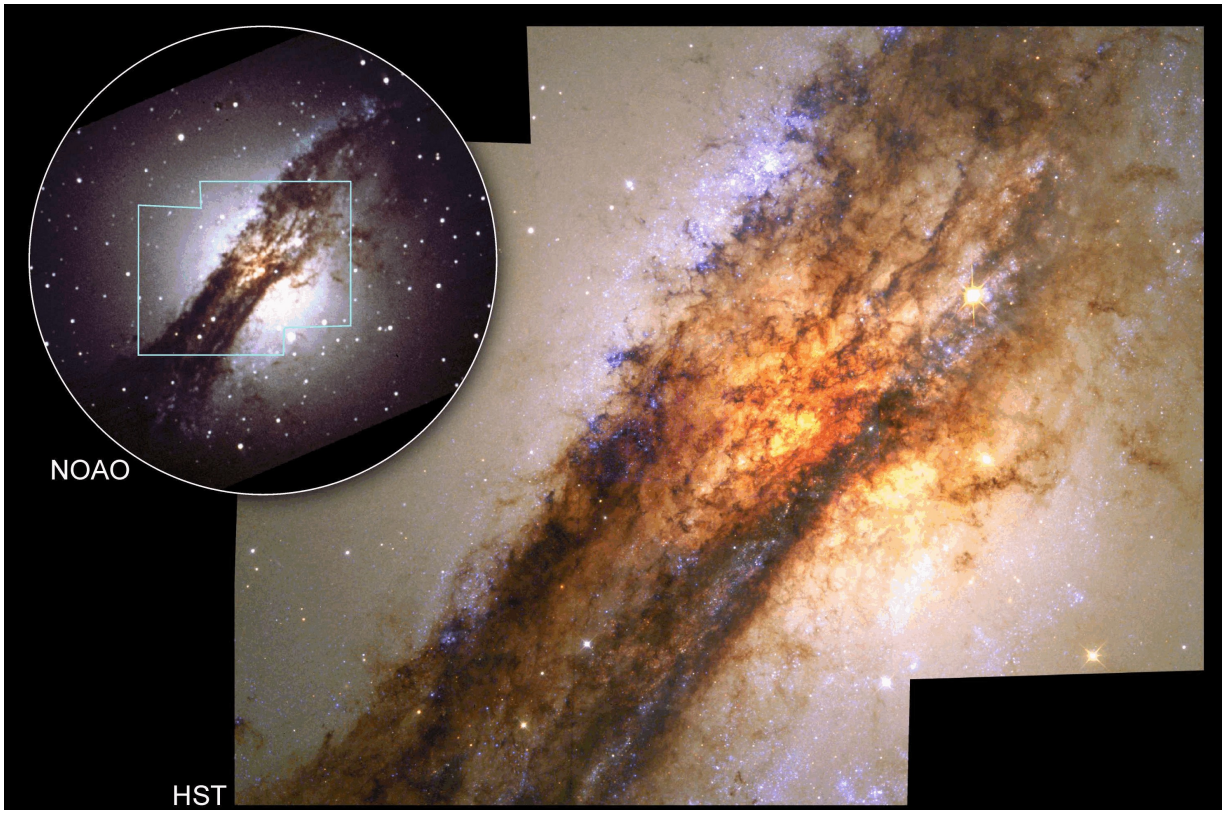
Velocity measurements of a disk of hot gas in the core of M87. The disk rotates at a speed of ~ 1.2 million miles per hour around a massive black hole weighing ~ 3×10^9 Solar masses.

Giant Dust Disk Around a Massive Black Hole



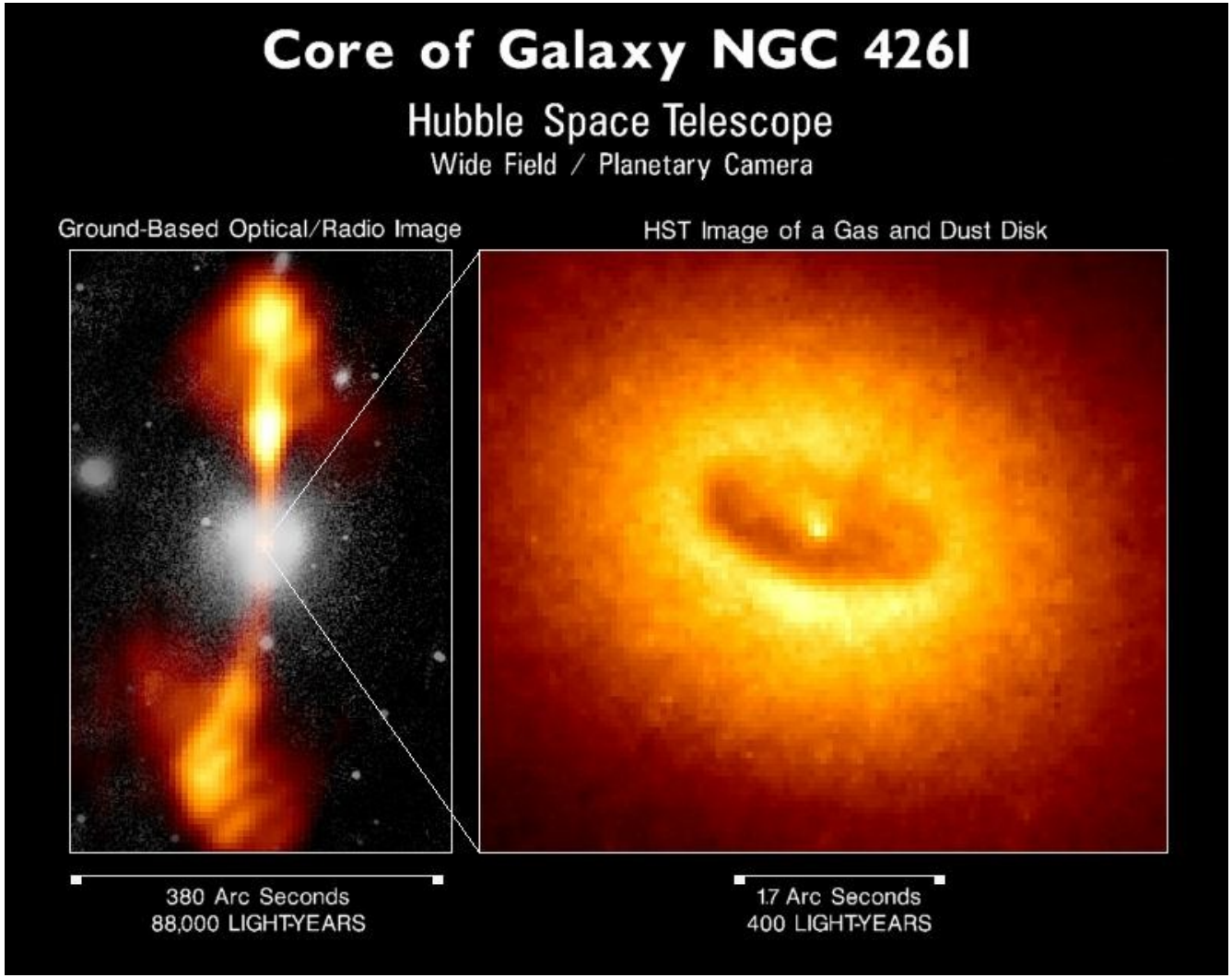
The 3,700 light-year-diameter dust disk that encircles a 3 x 10^8 Solar mass black hole in the center of the elliptical galaxy NGC 7052.

Feeding a Black Hole



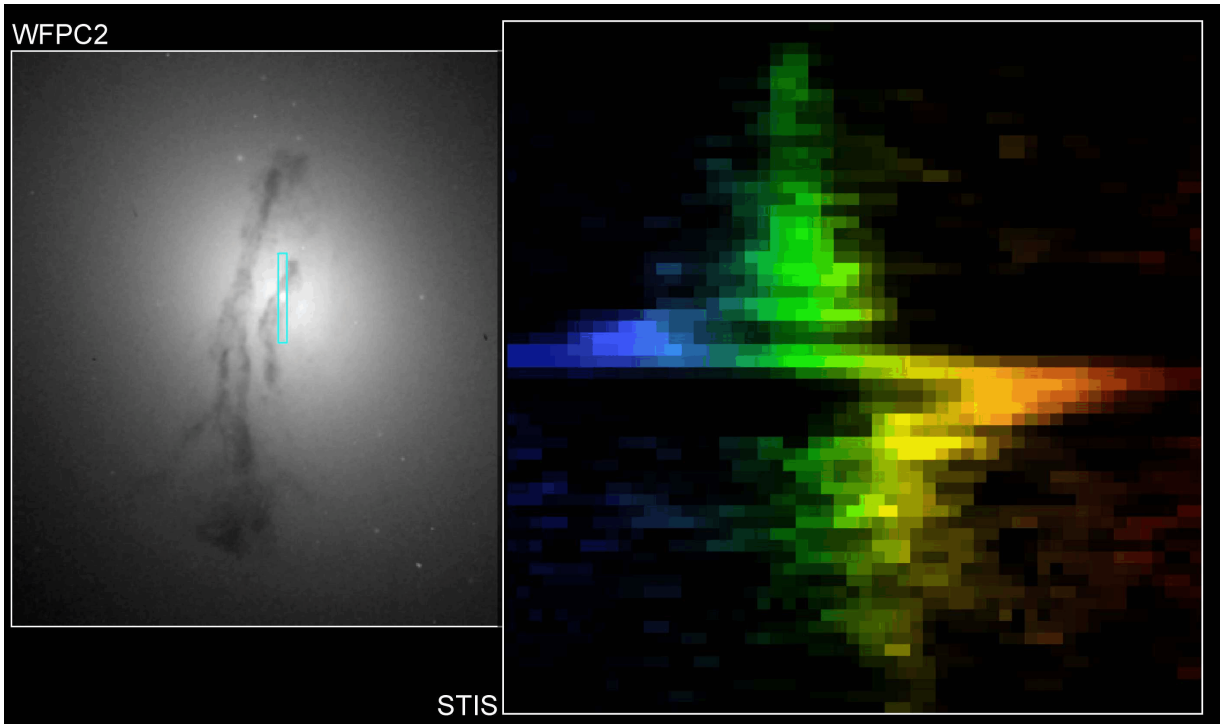
The "remnant" of a spiral galaxy that collided with the elliptical galaxy Centaurus A. The dust and cold gas provide fuel for the central black hole.

Dust Disk Around a Black Hole in NGC 4261



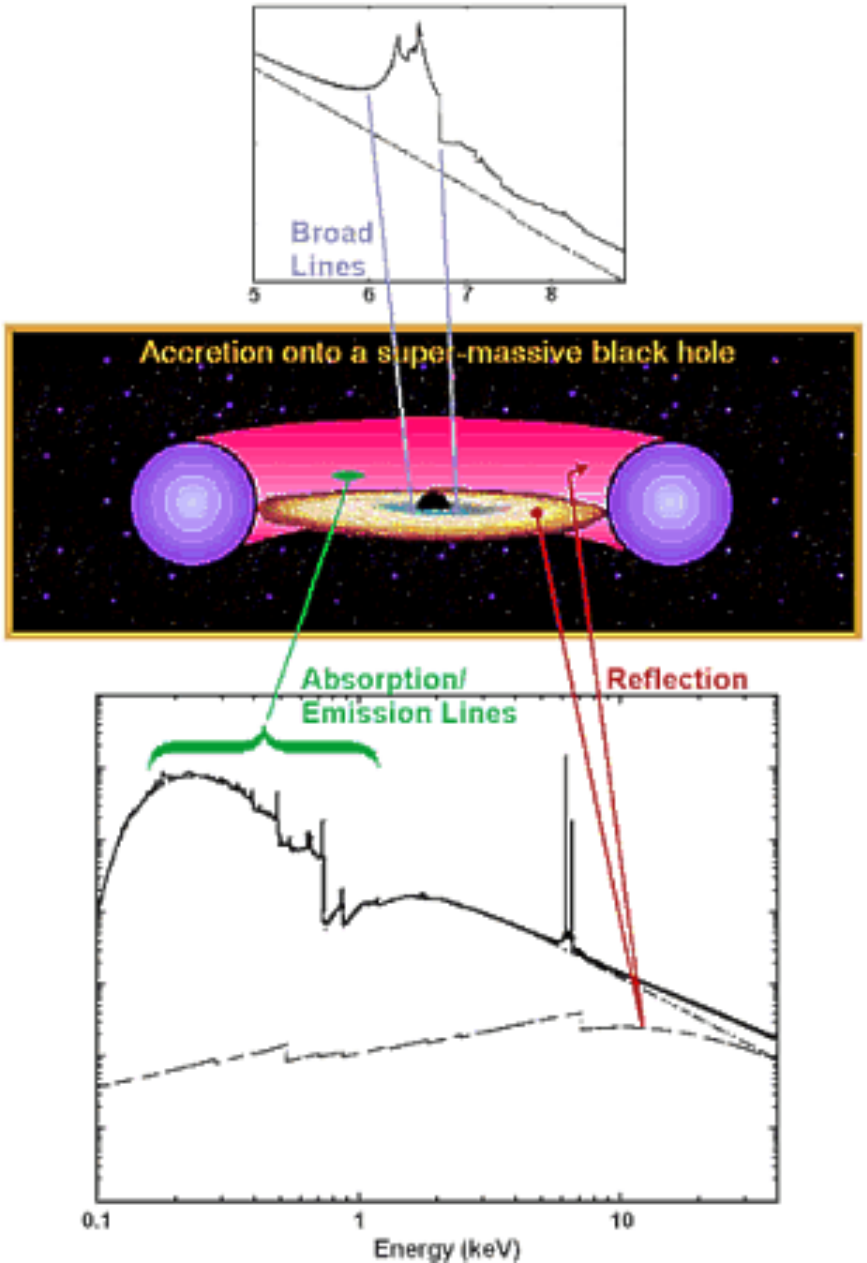
An HST image of an 800 light-year wide spiral shaped disk of dust fueling a 1.2 x 10^9 Solar mass black hole in the center of NGC 4261.

The Optical Spectral Signature of a Black Hole



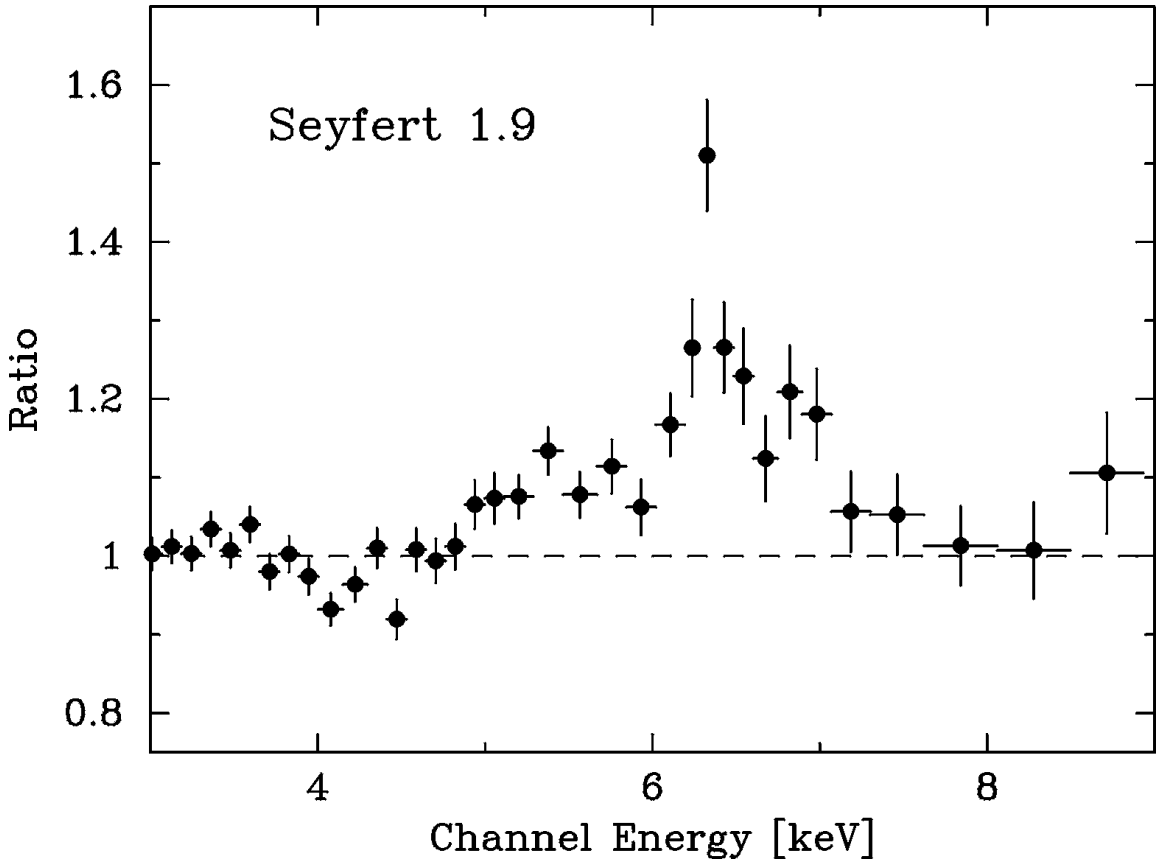
On the left is the core of the galaxy M84. The spectral scan box in light blue on the left shows stars and gas within 26 light-years of the galaxy's center rapidly swirling around a ~3x10^8 Solar mass black hole. The figure on the right represents the velocity of the swirling matter, with a dramatic reversal when the scan passes through the

AGN Engine Schematic



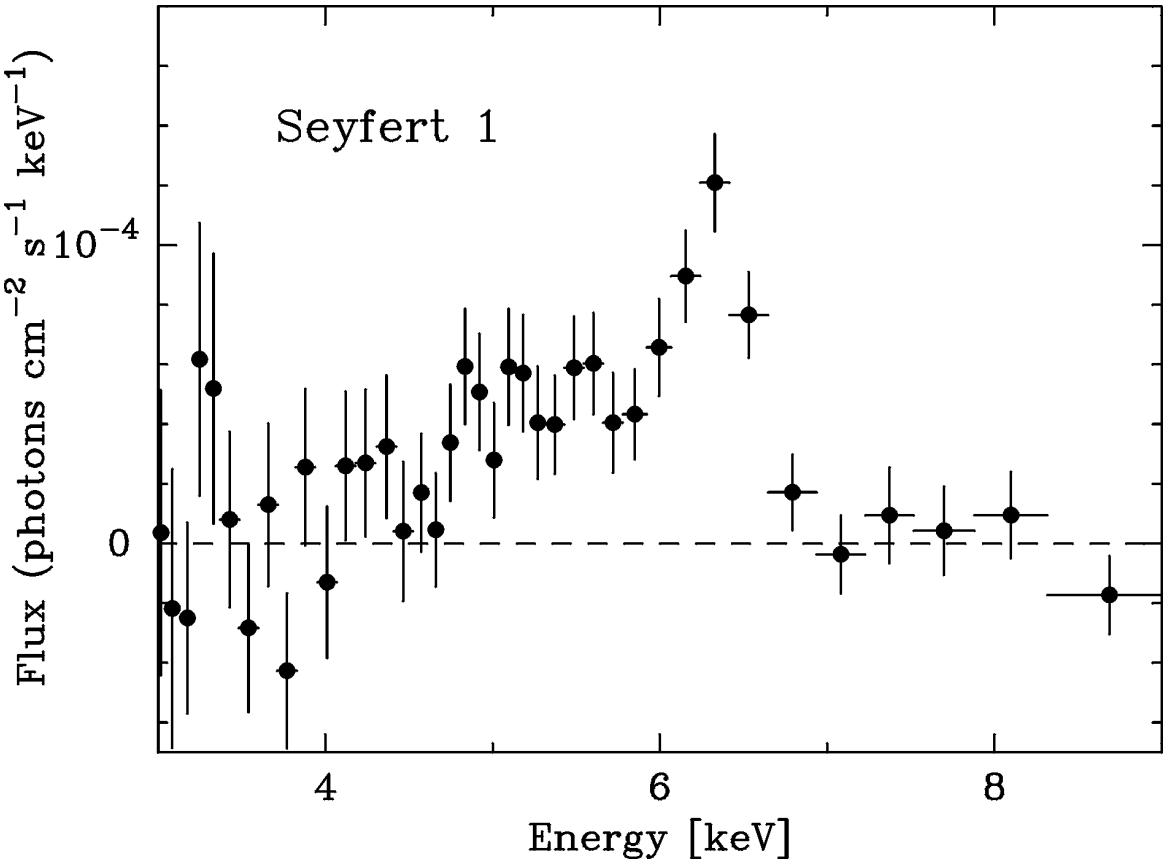
Schematic diagram of the regions of an AGN responsible for producing the observed X-ray spectral features.

Fe Line Structure in MCG-5-23-16



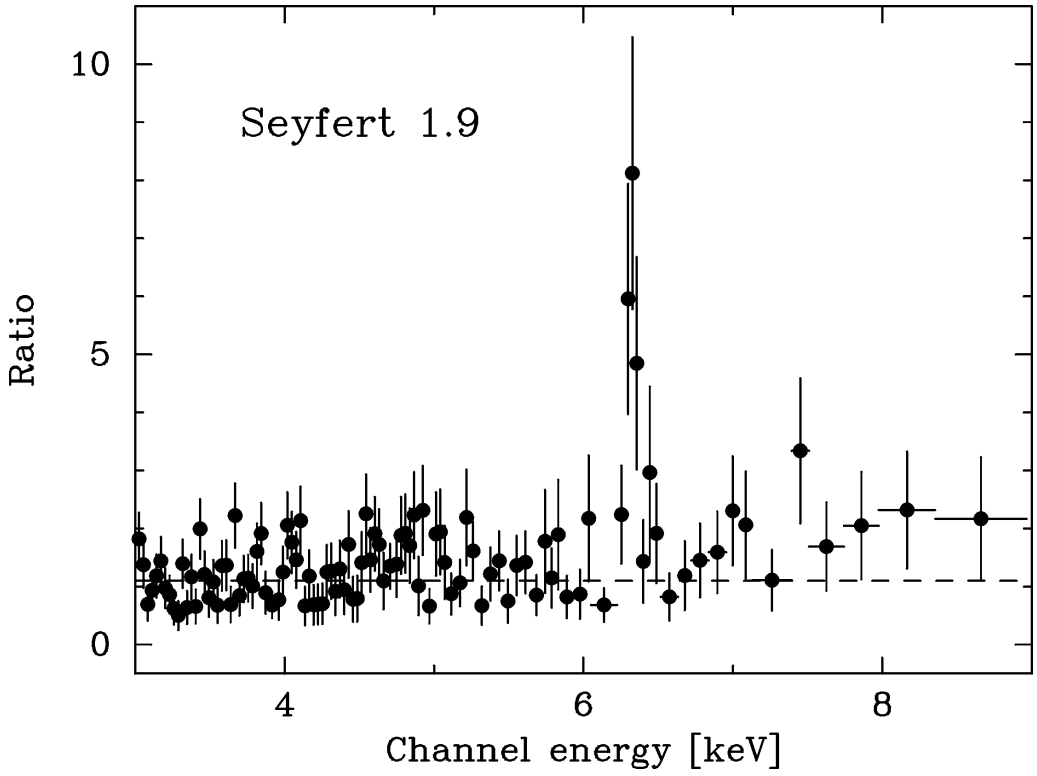
The triple-peaked iron line in the active galaxy MCG-5-23-16 indicates emission from an accretion disk plus emission from gas further out.

Broad Fe Line Emission in MCG-6-30-15



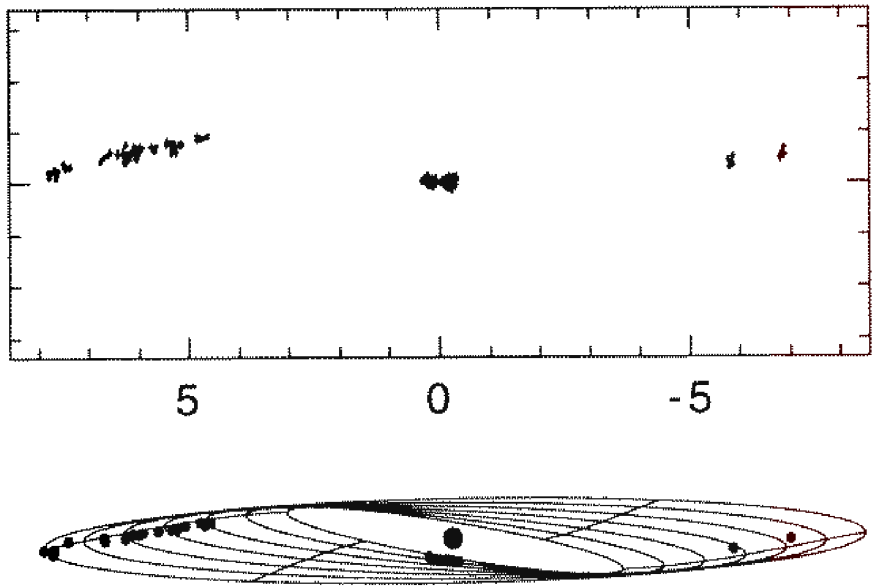
The very broad iron emission line in the active galaxy MCG-6-30-15 indicates emission from an accretion disk near the event horizon of a black hole (Tanaka et al. 1995, Nature, 375, 659).

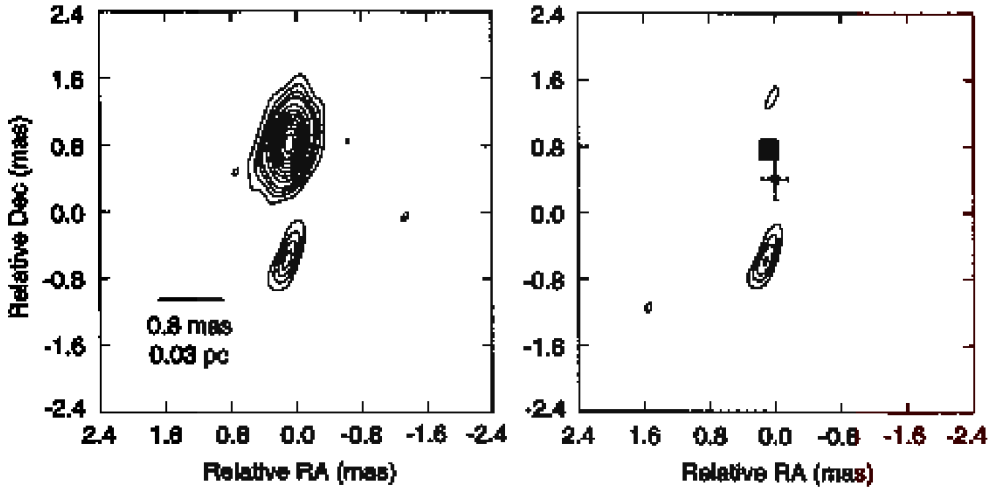
Narrow Iron K Emission Line from an Active Galaxy

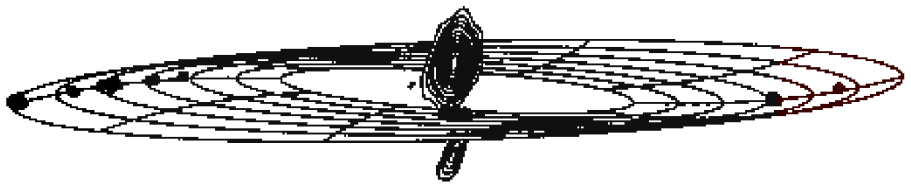


The narrow iron K emission line in the active galaxy NGC 2992 indicates emission from gas at approximately 3 pc (~ 9 light years) from the black hole (Weaver et al. 1996, ApJ, 458, 160). The gas is likely in the form of a large disk, similar to the one observed in NGC 7052.

The Case for a Black Hole in NGC 4258







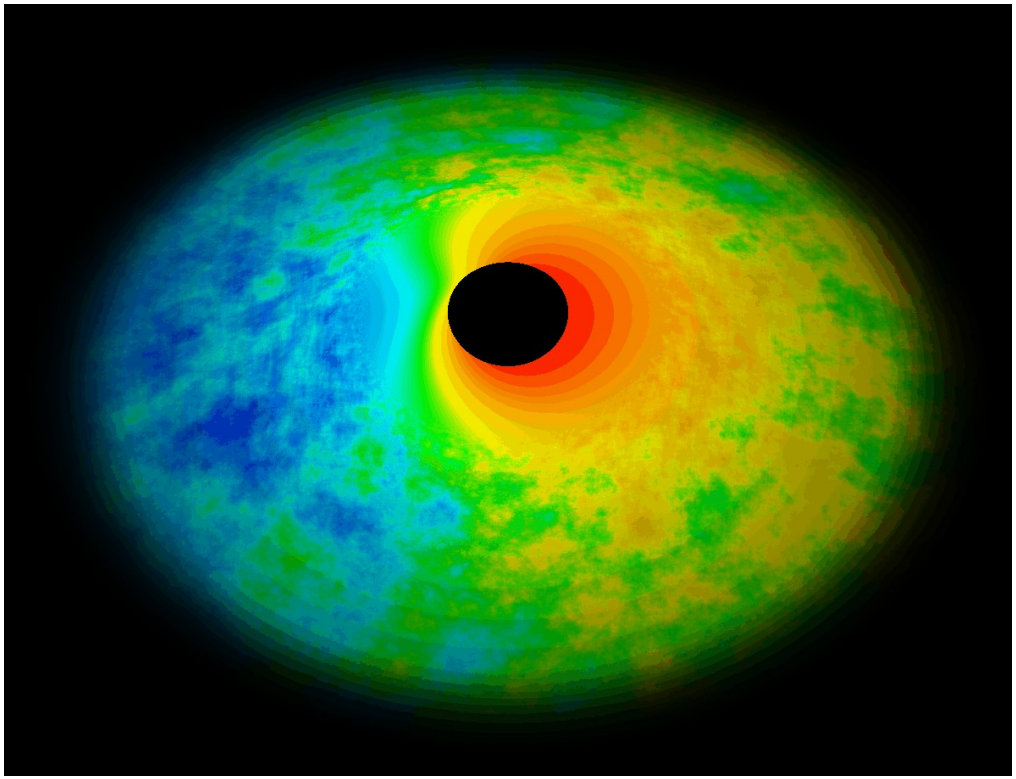
Panel 1: The disk-like distribution of the water masers in a sub-parsec region of NGC 4258 from Miyoshi et al. 1995 (Nature, 373, 127).

Panel 2: Warped disk model from Herrnstein, Greenhill & Moran 1996 (ApJ, 468, L17).

Panel 3 (left): 22 GHz VLBA continuum image of NGC 4258.
Panel 3 (right): image after deconvolving the northern jet emission.

Panel 4: continuum map superposed on the best-fitting warped-disk model

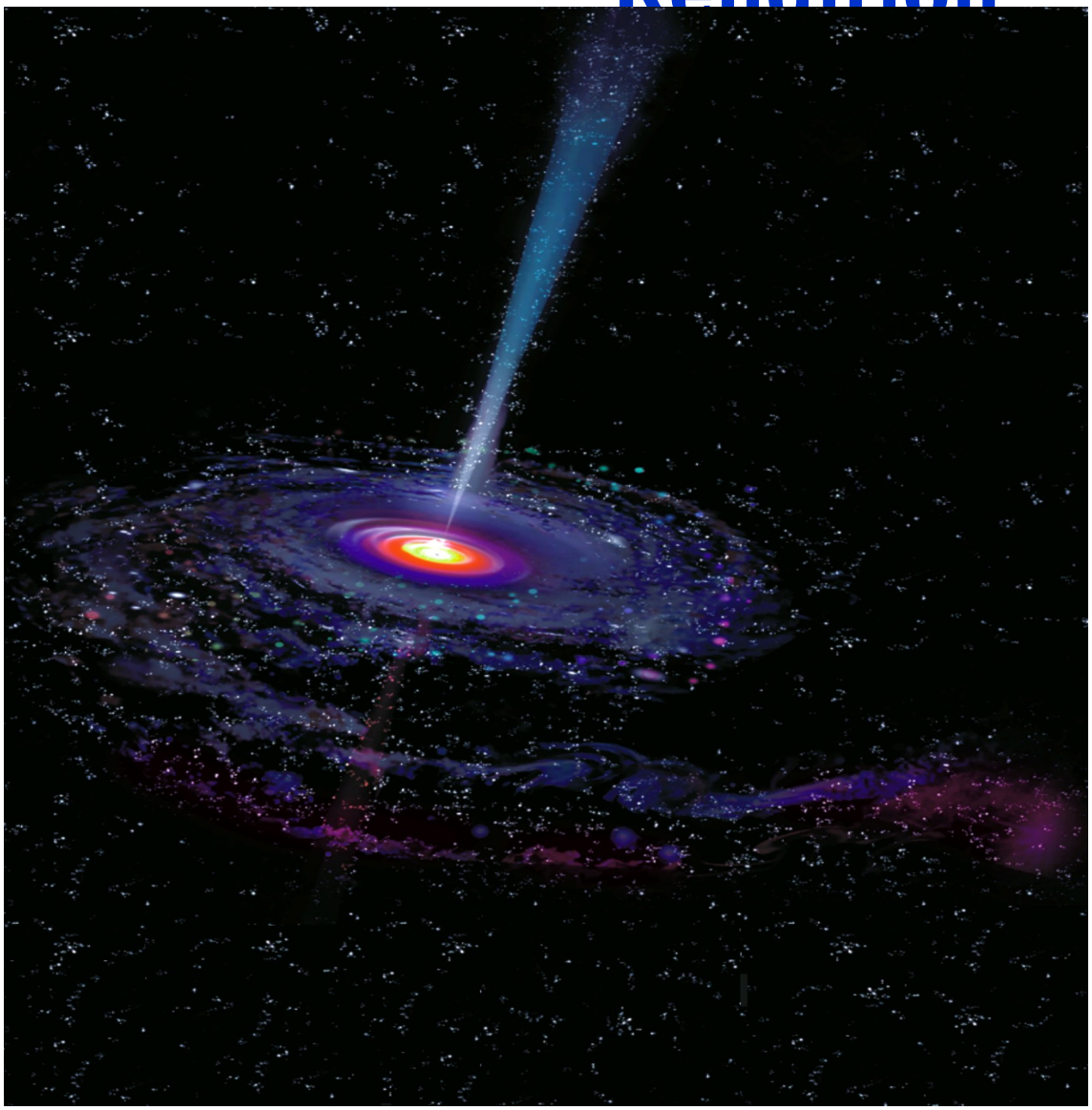
Theoretical Model of a Turbulent Schwarzschild disk



As the disk material loses angular momentum and accretes onto the hole, it generates the powerful radiation which we observe in active galaxies (Bromley, Miller and Pariev 1998, Nature, 391, 54).

The very broad iron emission line in the active galaxy MCG-6-30-15, is indicative of emission from an accretion disk surrounding a supermassive black hole.

Black Holes in Active Galaxies: Artist's Rendition



This artistic rendition illustrates how a black hole is fueled by the accretion of gas and dust which heats up and radiates strongly at UV and X-ray wavelengths. In some AGN, a jet of expelled plasma is formed which is often observed to move at velocities approaching the speed of light.